# Solar Mass Ejection Imager

George M. Simnett


School of Physics and Astronomy
University of Birmingham
Edgbaston, Birmingham  B15 2TT
United Kingdom

20 Feb 2002


Final Report
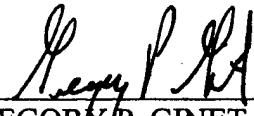
**AIR FORCE RESEARCH LABORATORY**
Space Vehicles Directorate
29 Randolph Rd
**AIR FORCE MATERIEL COMMAND**
Hanscom AFB, MA  01731-3010

" This technical report has been reviewed and is approved for publication."

CONTRACT MANAGER

GREGORY P. GINET, Chief
Space Weather Center of Excellence

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
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| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 20-02-2002 | Scientific, Final | 31 Jul 99--20 Feb 2002 |

**4. TITLE AND SUBTITLE**
Solar Mass Ejection Imager

**5a. CONTRACT NUMBER**
F19628-96-K-0005

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
612311; 69120J

**6. AUTHOR(S)**
George M. Simnett

**5d. PROJECT NUMBER**
7601

**5e. TASK NUMBER**
70

**5f. WORK UNIT NUMBER**
AC

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
School of Physics and Astronomy
University of Birmingham
Edgbaston, Birmingham B15 2TT
United Kingdom

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Air Force Research Laboratory/VSBXS
29 Randolph Road
Hanscom AFB, MA 01731-3010

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
AFRL-VS-TR-2002-1612

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
The University of Birmingham has designed, fabricated, qualified and calibrated the Solar Mass Ejection Imager to be flown on the Coriolis spacecraft. The hardware consists of three flight camera systems, plus a flight spare, and a complex data handling unit. The CCD camera was developed under subcontract by the Rutherford Appleton Laboratory, Chilton, UK. The SMEI has been thoroughly qualified to the requirements of the Coriolis mission. Each camera system has been optically calibrated to verify its pwerformance.

**15. SUBJECT TERMS**
Solar mass ejections    CCD camera    solar astronomy

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | Janet Johnston |
| UNCL | UNCl | UNCL | UNL | | 19b. TELEPHONE NUMBER *(include area code)* <br> 781 377-2138 |

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

# SOLAR MASS EJECTION IMAGER

## Report for the SMEI Hardware Phase 1996 - 2001

## G.M. Simnett

## School of Physics and Astronomy, University of Birmingham, B15 2TT, UK

**Overview:**

Under contract F19628-96-K-0005, the University of Birmingham has designed, fabricated, qualified and calibrated the Solar Mass Ejection Imager (SMEI) to be flown on the Coriolis spacecraft. The hardware consists of three flight camera systems, plus one flight spare, and a complex data handling unit. Two optical mirror components and a vane, for each of the four camera systems, were supplied by the University of California, San Diego (UCSD). The key to the performance of SMEI is the design of the optical system, which must reduce stray light levels below around $10^{-15}$ of the solar irradiance. This is equivalent to the brightness of a $10^{th}$ magnitude star per square degree. The primary mission objective of SMEI is to track coronal mass ejections which leave the Sun and to provide an early warning if they are likely to hit the Earth. A secondary objective is to monitor brightness changes of all objects in the sky brighter than $10^{th}$ magnitude, the Sun and planets excepted.

The theoretical optical design was performed prior to the start of this contract by UCSD, and the stray light rejection is achieved through the use of a blackened baffle and a black camera cavity, containing a CCD chip. The optical system images a strip of the sky approximately 63° × 3° onto the CCD. The image is slightly defocussed to reduce the possible effects of sub-pixel gradients in the CCD response.

The CCD camera has been developed under subcontract by the Rutherford-Appleton Laboratory, Chilton, UK. It uses an EEV CCD 05-30-0-231A chip operating in a frame transfer mode. The SMEI instrument uses three cameras, mounted on the spacecraft such that they view virtually all the sky once per orbit (96 minutes). The region within 18 degrees of the Sun is avoided by using a shutter controlled by a bright object sensor and a small region in the antisolar direction is also not imaged. The three cameras are operated through a computer based data handling unit (DHU) which formats the data for transmission by the spacecraft telemetry, processes instrument commands, and formats the housekeeping and engineering mode data.

The mechanical and thermal properties of the instrument have been evaluated theoretically and the results have been utilised in the flight hardware design. The instrument has been throughly space qualified to the requirements of the Coriolis mission. Each camera system has been optically calibrated to verify its performance.

Following a final readiness review in Birmingham in April 2001, the flight instrument was delivered to Spectrum Astro, in Phoenix, Arizona, on 18 April 2001. The flight hardware, which includes the three cameras and the DHU, is shown in Figure 1.
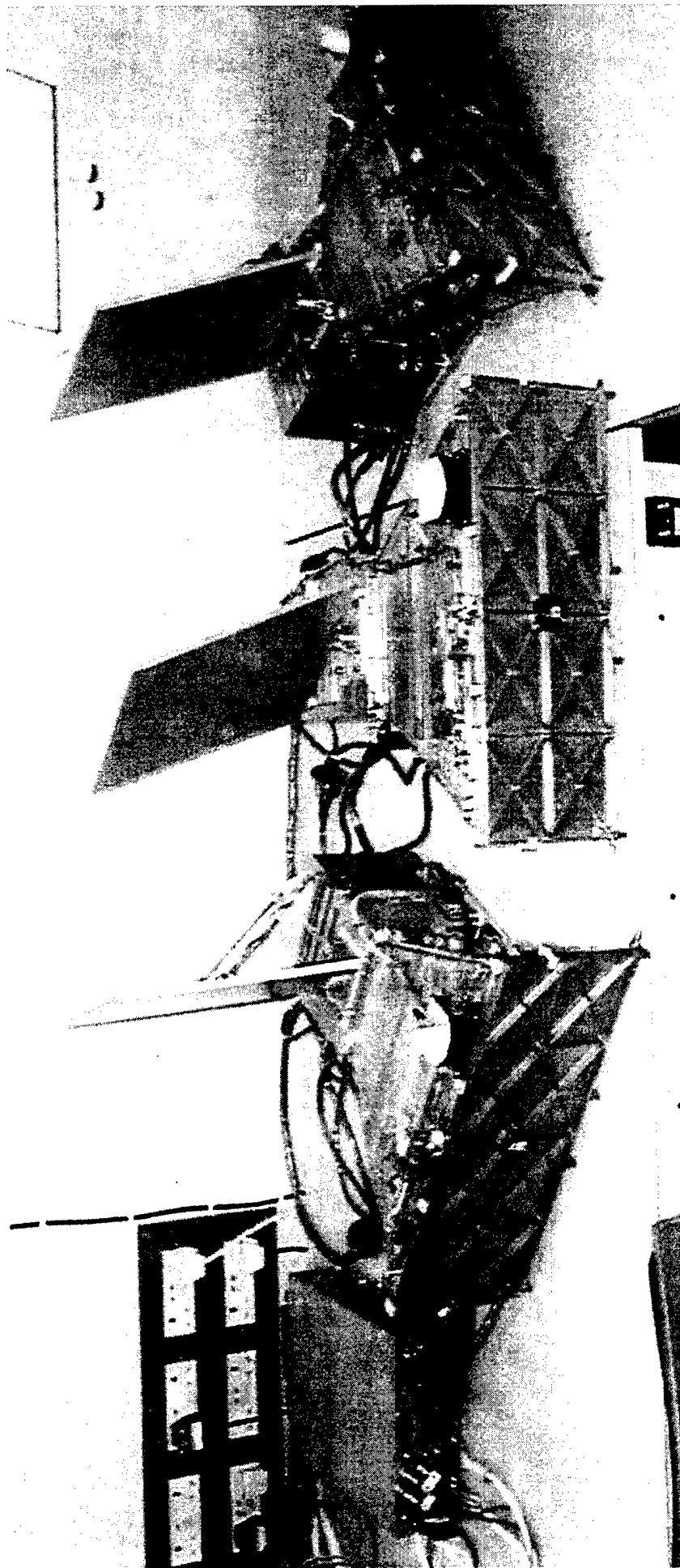
Figure 1.    Three flight camera systems and the DHU

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## Mechanical Design:

The mechanical design centered around the structure of the optical baffle, which has eight critical vanes. In order to meet the stray light rejection criteria, the interior of the complete baffle needed to be coated with Martin Black, a proprietary coating made by Lockheed-Martin Astronautics, Denver, CO. Consequently the baffle was manufactured in eight sections, each of which was then blackened. The eight sections were then fastened together and held in place by tensioning struts along each of the four corners. IDEAS software was used to verify the integrity of this design. A critical part of the design was the requirement that the joints between the baffle sections be completely light tight.

The interface of each camera with the spacecraft is through the main optical chamber which contains the mirror components and the CCD. Four faces of the optical box are utilised, one for the baffle, one for the CCD electronics, one for the spacecraft interface and one for the passive radiator to cool the CCD chip. The mechanical design of the optical chamber and the CCD electronics box was aided by the desirability of having a significant wall thickness to assist in the radiation shielding of the electronics and CCD chip.

Each camera is protected following final assembly by a door, which is kept closed apart from a short time during testing when the release mechanism is operated. The doors are re-latched as soon as possible following tests. The CCD must be kept dust free at all times, as there is no opportunity for cleaning following final assembly. The door mechanism is released by a High Output Paraffin (HOP) actuator and there are kick-off springs and hinge springs to ensure reliable opening of the door to the designed limit.

The structural analysis was performed theoretically using the IDEAS software package. This demonstrated that the structural design was sound and the the resonance frequencies of the structure were all above 75 Hz.

## Thermal Analysis:

The thermal analysis was difficult due to the fact that until the spring of 1998 the spacecraft on which SMEI would ride was not known; neither was the orbit. In the spring of 1998 SMEI was manifested on the Coriolis spacecraft, which is to be launched into a near polar orbit from Vandenburg Air Force Base, on a Titan II launch vehicle. A year later Spectrum Astro was awarded the contract for building the Coriolis spacecraft. It was not until the spacecraft accommodation was determined that the thermal analysis could be completed.

The CCD chips are designed to operate at -35°C or cooler. Once the accommodation of SMEI on the spacecraft was defined, the details of the cooling system could be finalised. Each camera is cooled by an individual passive radiator, and calculations using the THERMICA software package were used to establish the optimum size and location of the radiators.

## Data Handling Electronics:

The data handling unit is a microprocessor-based system utilising the Texas Instruments TXS320C50 processor. The processor is operated at a frequency of 19 MHz, which gives a typical capability with the SMEI on-board software of around 10 MIPS. The system contains: (a) 128k × 8 bits of EPROM, which contains (redundantly) the operating software. Following integration, this memory is operated as a ROM. (b) 0.5 M × 16 bits of EPROM, into which command tables, software patches, sequencer tables, region of interest maps, etc., may be loaded. This memory is protected if SMEI is powered down. (c) 1M × 16 bits of RAM, into which images and flat field tables are loaded.

The tasks of the DHU are as follows:

(1) The receive commands from the ground via the spacecraft

(2) To receive images from the three SMEI cameras

(3) To make a flat field correction using a look-up table which can be uploaded from the ground if necessary.

(4) To select the instrument mode. SMEI has three modes of operation: (a) a normal observing mode, where camera images are taken; (b) a configuration mode, which is used to select observing and instrument configurations; thermal control settings can also be changed in this mode; (c) a safe mode, where the shutters will be commanded closed and power requirements reduced to a minimum.

(5) To format the image and housekeeping data for the spacecraft telemetry.

(6) To control the heater power for the camera heaters.

(7) To activate the HOPs at the start of SMEI observations following launch.

The 1M × 16bit solid state memory is sufficient to store one flat field table and three consecutive mapped images.

In the observing mode there are three possibilities. The normal mode has 4 × 4 CCD pixel binning over the imaged area of the CCD; the high resolution mode has 2 × 2 CCD pixel binning; while in the engineering mode all pixels from the selected readout area are transmitted.

Communication with the spacecraft is via a MIL-STD-1553B data bus.

## On Board Software:

The on-board software is designed to run SMEI, under command, in any of its designed operating modes. The program occupies just under 16k bytes of the (EP)ROM, which contains 8 identical copies. There is provision to upload software patches into the 0.5Mword EPROM. The operating system was completed in late 2001 and finally put into the (EP)ROM in November, 2001. A full description of the on-board software is expected to be available before launch. In the normal observing mode the system is designed to

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handle one image every 4 seconds from each camera, corrected for the latest flat field. The telemetry rate is 64 kbps.

## Quality Assurance:

The CCD chips were procured with vibration and thermal cycling screening in accordance with MIL-STD-883 level B. The integrated circuits were procured to MIL-STD-883 level B, or equivalent, or higher. Transistors and other active devices were procured to JANTX or JANTXV, or higher. Passive components were procured to MIL-STD Level R or S, ESA SCC-level C, or equivalent.

Full incoming inspection records have been kept at the University of Birmingham.

The electronic component types which were procured without a radiation tolerance to at least 20krad were tested in Birmingham with a $Co^{60}$ source. Any component type which showed any parametric failure below 20 krad was protected in the flight model with a local tantalum shield. Thus the SMEI electronics is designed to tolerate a radiation dose in excess of 20 krad.

## Cleanliness:

The primary concern in cleanliness is the interior of the baffle, the mirror surfaces and the CCD chip. The baffle sections were shipped with individual shipping containers which were double bagged to prevent ingress of contaminants following application of Martin Black. Figure 2 shows one of the blackened baffle sections in the class 1000 clean room in Birmingham. Assembly and optical testing of the flight unit cameras, including the flight spare unit, was carried out in the class 1000 clean room. The units were inspected under a UV light, and any dust particles identified were removed by a vacuum suction device.

## Space Qualification:

SMEI has been thoroughly space qualified. The vibration tests were performed on the engineering model to DMSP qualification levels. The flight components were vibrated to DMSP acceptance levels. Figure 3 shows one of the flight model cameras mounted on the vibration jig. The electronics system has undergone a burn-in of 600 hours. The flight model has been tested under thermal vacuum conditions, which included 6 cycles with 6 hour soaks at each extreme. EMI/EMC tests were based on MIL-STD-461D.

The applicable documentation describing these tests is the Spectrum Astro Interface Control Document (ICD) 1131-E1-Y15057 Appendix B.

## Optical Calibration:

Each of the four cameras was tested optically using a procedure developed at UCSD and under their direction. The results have enabled the flat field tables to be generated.
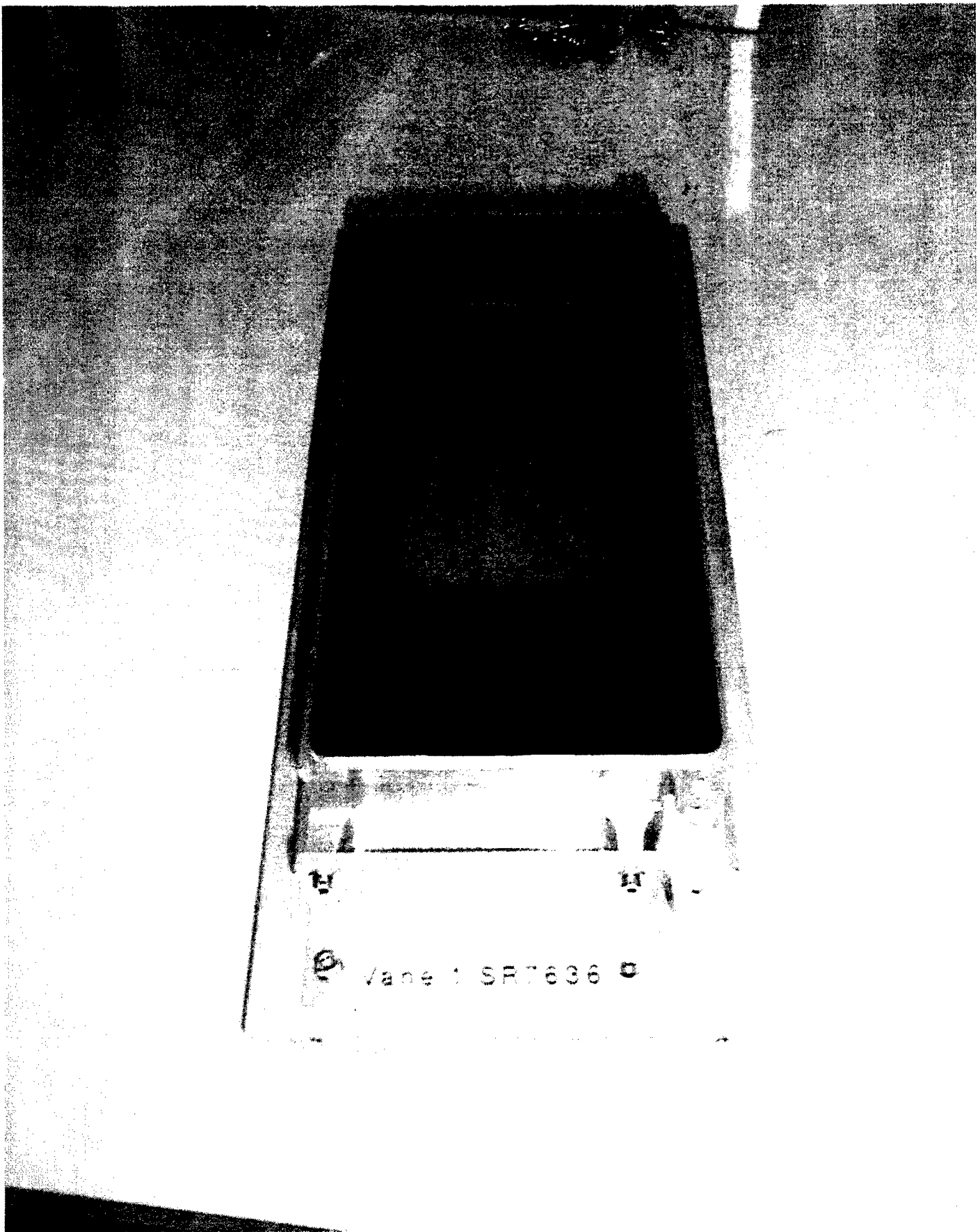
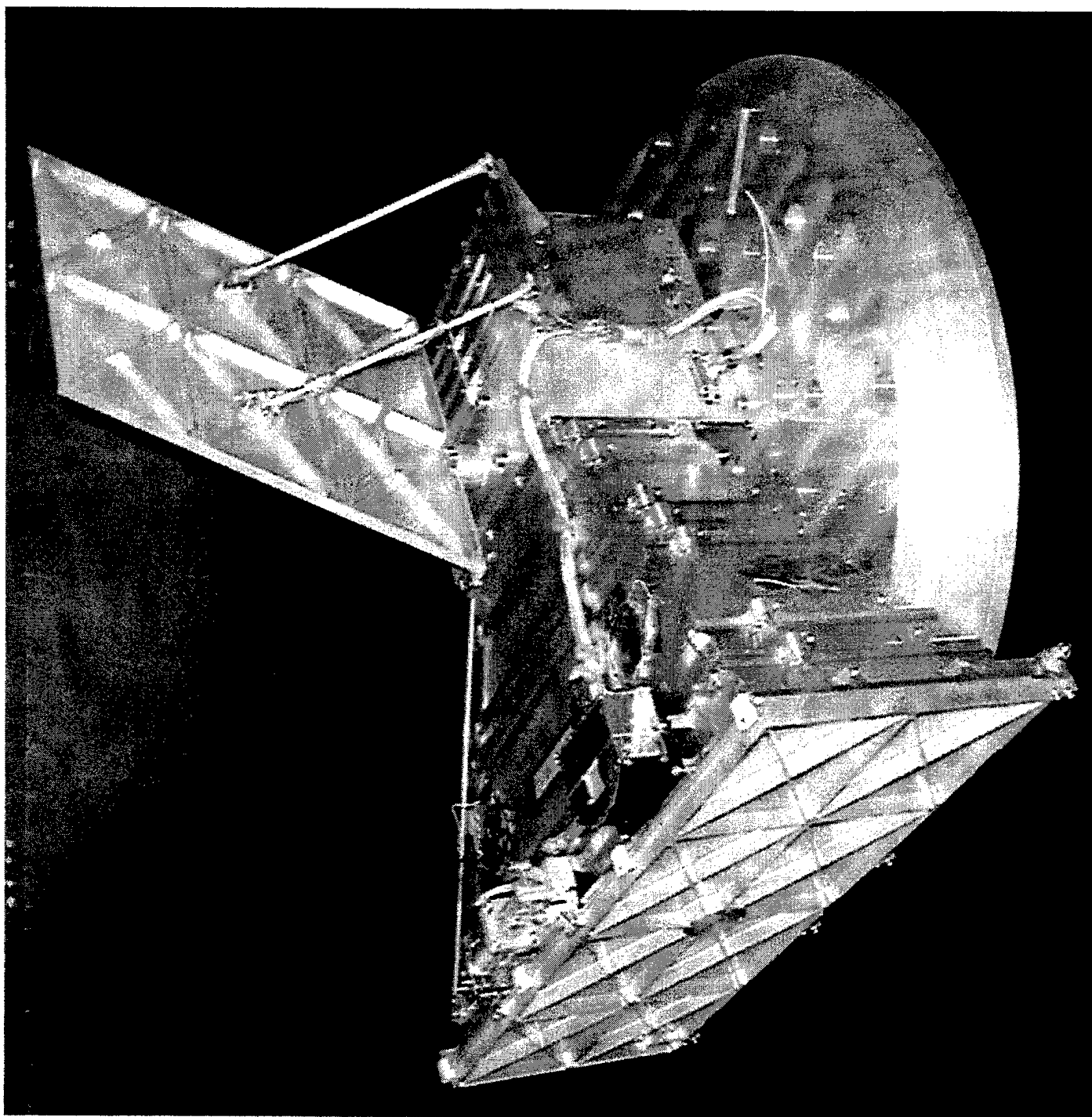Figure 2. The top baffle vane after blackening

Figure 3.   A flight camera system mounted on the vibration jig

An optical calibration system is also built into each camera in the form of a calibrated light-emitting diode which can illuminate a specially prepared surface on the back of each shutter.

## Ground Support Equipment:

The ground support equipment includes a PC to provide a 1553B spacecraft simulator, to enable SMEI to be operated in realistic data acquisition mode. Additional special purpose GSE includes a CCD camera driver; a spacecraft power supply, command and relay switching simulator; bright object sensor stimulators and an HOP reset tool.

SMEI was shipped to Spectrum Astro, Arizona, in a sealed shipping container, designed and certified for air shipment.

## Reviews:

There have been four formal reviews during the SMEI project, all of which took place at the University of Birmingham.

(1) System Requirements Review, 10 July 1996
(2) Preliminary Design Review, 24-25 March 1997.
(3) Critical Design Review, 17 August 1999
(4) Flight Hardware Acceptance Review, March/April 2001

## Applicable Documents:

The following documents are applicable to SMEI:
(1) ICD 1131-EI-Y15057 Appendix B (Spectrum Astro)
(2) SMEI Commanding Protocol SMEI/BU/SPE/001 M.P.Cooke and C.J. Eyles (2001)
(3) SMEI Commanding Specification SMEI/BU/SPE/002 M.P.Cooke and C.J. Eyles (2001)
(4) SMEI Telemetry Format Specification SMEI/BU/SPE/003 M.P.Cooke and C.J. Eyles (2001)
(5) SMEI On-orbit Procedures SMEI/BU/PRO/007 M.P.Cooke and C.J. Eyles (2001)

These are (except the Spectrum Astro ICD) all available from the University of Birmingham SMEI Website:

http://www.sr.bham.ac.uk/ mpc/pulsar/smei

or the ftp site:

ftp://pc1.sr.bham.ac.uk/pub/smei/docs